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Landscapes of Settlement in Northern Iceland: Historical Ecology of Human Impact and Climate Fluctuation on the Millennial Scale

ABSTRACT Early settlement in the North Atlantic produced complex interactions of culture and nature. The sustained program of interdisciplinary collaboration is intended to focus on ninth- to 13th-century sites and landscapes in the highland interior lake basin of Mývatn in Iceland and to contribute a long-term perspective to larger issues of sustainable resource use, soil erosion, and the historical ecology of global change. [Keywords: Iceland, sustainability, historical ecology, paleoecology]

INTRODUCTION: NABO, GLOBAL CHANGE, AND HISTORICAL ECOLOGY IN THE NORTH ATLANTIC

Near the close of the eighth century C.E., Nordic pirates, traders, and settlers began the expansion from their Scandinavian homelands that gave the Viking Age its name and permanently changed the development and history of Europe. In the North Atlantic, by circa C.E. 800–C.E. 850, settlers colonized the islands of the eastern North Atlantic (Shetland, Orkney, Hebrides, Man, Ireland, and Faroes). Iceland was traditionally settled circa 874, Greenland circa 985, and the short-lived Vinland colony survived for a few years around C.E. 1000 in Newfoundland–Gulf of St. Lawrence region (Arneborg 2000; Wallace 2000). Around the year C.E. 1000, Nordic language and culture extended from the coast of North America to the Baltic, and by C.E. 1014 an Anglo-Scandinavian dynasty briefly united England, Denmark, and Norway. However, this first connection of old and new worlds proved transient. By the mid-11th century the Vinland colony was abandoned, and by the mid-15th century the Greenlandic colony became completely extinct. Iceland survived as the westernmost outpost of the Viking Age North Atlantic expansion, and the first transatlantic connection between the Old and New Worlds ended in failure. Changes in politics and market forces in Europe played a role in the unhappy end to the “Norse Atlantic

Saga” (Jones 1986), but climate change and human environmental affects on island ecosystems were also an important part of the story (Amorosi et al. 1997, 1998; Dugmore et al. 2004; Ogilvie and McGovern 2000).

Prior to the 1970s, most scholars of the Viking period were philologists, medieval archaeologists, and documentary historians, and the uneven written record for Viking depredations in Europe and Iceland’s colorful and diverse saga literature tended to dominate discussion of the period (for research history, see Friðriksson 1994). Since the mid-1970s research focus has shifted, as multiple projects combining archaeology, paleoecology, and history have been carried out all across the region, producing a richer understanding of the Norse migrations and placing them more effectively in an environmental and economic context (Arneborg and Grønnow 2005; Bigelow 1991; Housley and Coles 2004; McGovern 1990, 2004; Morris and Rackham 1992; Ogilvie and McGovern 2000). The historical ecology movement (Baleé 1998; Crumley 1994, 1998, 2001; Kirch and Hunt 1997) has come to provide the theoretical underpinning of much North Atlantic archaeological research, a pattern shared by many other regions where archaeology and paleoecology are attempting to connect the long-term record of human–environment interaction with present issues of rapid environmental change and human

response (Hardesty and Fowler 2001). The movement attempts to combine the interdisciplinary environmental orientation of the best of the processual archaeology of the 1980s with the concern for contextual history, factional conflict, and politically loaded cultural landscape construction stressed by some postprocessualists in the 1990s—with a clear agenda aimed at integrating archaeology and environmental history within global change research (Amorosi et al. 1996; Bawden and Reycraft 2001; Descola and Pálsson 1996; Kirch 1997; McGovern 1994; Redman 1999; Spriggs 1997; Steadman 1995).

The dramatic value of the diverse cases provided by the Norse North Atlantic (initial spread of a homogeneous population into different island ecosystems, subsequent economic and social diversification, and total extinction of the Vinland and Greenland colonies) has increasingly featured in works aimed at a broad audience interested in global change topics (Diamond 2005; McGovern and Perdikaris 2000; Pringle 1997; Redman 1999). In the past decade, the North Atlantic has thus become an arena for just the sort of international, interdisciplinary research into long-term, human–environmental interactions that most funding agencies identify as worthy of global change support. This development is itself in part an outcome of early global change funding to archaeology and paleoecology by the U.S. National Science Foundation's Office of Polar Programs (NSF OPP).

The regional research cooperative North Atlantic Biocultural Organization ([NABO], see www.geo.ed.ac.uk/nabo) was formally set up at an NSF supported workshop 1992, but it initially grew out of a meeting in 1988 at Bowdoin College hosted by Gerry Bigelow and Susan Kaplan of the Peary-Macmillan Arctic Center (Bigelow 1991). Since 1993, NABO has provided support for field projects in Iceland, Greenland, Northern Norway, Scotland, and the Faroe Islands. The group has contributed to Northern education by sponsoring doctoral, Master of arts, and Master of science theses in anthropology, geology, and geography in the United States, United Kingdom, and Scandinavia, and since 1997 has cosponsored (with City University of New York [CUNY], the Icelandic Institute of Archaeology, University of Oslo, and University of Glasgow) an international multidisciplinary field school in Iceland that has involved students from 26 nations. Since 2000, a special NSF OPP Research Experience for Undergraduates grant to Sophia Perdikaris of Brooklyn College, CUNY, has integrated classroom, laboratory, and real-time distance learning, with Icelandic fieldwork, dramatically changing the lives of highly motivated inner-city undergrads and producing a series of student-authored papers and posters (Amundsen et al. 2005; Krivogorskaya et al. 2005). NABO has also provided practical logistic support (three jointly purchased and maintained Land Rovers, jointly purchased resistivity instruments, electronic distance meters [EDMs], and GPS receivers, and prepositioned stocks of basic field gear, tents, and provisions), has provided enhanced data comparability through community devel-

oped data management software (NABONE), and has held a suite of 22 workshops and conferences since 1992 that have helped forge individual and institutional connections and produced major conference publications (Arneborg and Grønnow 2005; Bigelow 1991; Housley and Coles 2004; Morris and Rackham 1992; Ogilvie and Jónsson 2001). NABO interdisciplinary efforts produced the first use in archaeology and history of high-resolution proxy climate data from the Greenland ice-core projects (Barlow et al. 1997; Buckland et al. 1996; Dugmore et al. forthcoming), and NABO meetings now regularly include representatives of the hard sciences and environmental planners, as well as the usual crowd of historians, archaeologists, and paleoecologists. NABO teams have also been successful in leveraging the initial NSF support to a current total of just over US\$3.5 million in external funding from North American, Scandinavian, and United Kingdom sources. NABO participants have gotten by with help from their friends and neighbors and have been able to take on projects and address problems beyond the capability of any single scholar, university, or national research program.

CASE STUDY: EARLY SETTLEMENT IN NORTH ICELAND

Although one objective of this article is to indicate the general benefits (scholarly and financial) of sustained, active, and coordinated interdisciplinary international cooperation, the only real justification for involvement in the acronym-rich world of Global Change research is the improvement of our collective contribution through case-specific, problem-focused field and laboratory research projects. The remainder of this article turns to a presentation of the results of one of the largest and longest-lasting cooperative NABO projects: the "Landscapes of Settlement in NE Iceland" project (1996 to present) in the inland Mývatn district (Mývatnssveit).

Iceland is a volcanic island situated atop the North Atlantic ridge. It is subject to frequent volcanic eruptions, many of which provide a widespread fallout of volcanic ash (*tephra*). Where identified, these tephra layers define isochronous marker horizons that can be traced through sediment, soil profiles, and archaeological deposits (Dugmore et al. 2004; Thórarinnsson 1944, 1961, 1981). Southern Iceland is warmed by the North Atlantic drift and is classed as a boreal environment (with little persistent snow in lower elevations). Northern Iceland is significantly colder (low arctic, substantial long-lasting winter snow), and the interior highlands are today covered by large glaciers and heavily eroded arctic deserts.

Accounts of early settlement by Celtic Christian monks are still unproven by archaeology (but see Ahronson 2000), and archaeological evidence strongly indicates the first effective settlement of the island by humans occurred in the late ninth century C.E. (conveniently associated with the "Landnám" tephra layer now dated C.E. 871 \pm 2 by correlation to the Greenland Ice Sheet; see Grönvold et al.

1995). When Scandinavian settlers arrived, they encountered a mid-Atlantic island with substantial arctic birch forest in the lower elevations, coastal sea mammal (including walrus) and sea bird colonies, migratory nesting birds, and the green grass that could feed their imported domestic livestock. The economy of the Viking Age North Atlantic settlers was flexible but based around stock raising supplemented by limited barley growing and often extensive use of wild species (Dugmore et al. 2005; McGovern et al. 2001; McGovern et al. 2006; Simpson et al. 2002). Pasture was the ultimate source of wealth and power, and the correlation of cattle, good grazing, and chieftainship is clear in both the historical and archaeological record (McGovern 2000; Vésteinsson 1998). Between the initial settlement (Landnám), traditionally dated circa C.E. 874, and political union with Norway in 1262, Icelandic society was dominated by chieftains and great families but constrained by codified laws and an elaborate system of traditional justice (Sigurðsson 1999; Vésteinsson 2000a, 2000b, 2001). Although today Iceland is an independent, vibrant, rapidly urbanizing modern Scandinavian nation of around 300,000, during the 15th–18th centuries Iceland was a relatively impoverished rural province in the kingdom of Norway–Denmark with a population fluctuating around 50,000.

Like many of the islands of Oceania and the Caribbean, Iceland thus represents an environment with a clear and relatively recent prehuman–human baseline, but Iceland would also become a fully literate island community whose natives were to produce some of the most important histories of early medieval Scandinavia and self-consciously antiquarian records of pre-Christian pagan mythology. Iceland also has a long modern tradition of scholarship in both the natural and social sciences, particularly in history, anthropology, and the earth sciences. Icelandic medieval literature (sagas, hagiographies, histories, annals, law codes, etc.) provides a rich record of later landholding patterns, legal practice, stock raising, demography, conflict and competition, and invaluable access to an internal world view and emic social and economic categories that have been heavily exploited by anthropologists and social historians (Byock 2001; Durrenberger 1989, 1992; Eggertsson 1998; Hastrup 1985, 1990; Ingimundarson and Ogilvie 1998; Miller 1990; Ogilvie 1997; Vasey 1991, 1996; Vésteinsson 2000b). Particularly useful for economic history and settlement pattern analysis is a comprehensive land and stock register compiled in 1703–12 (Jarðbók Árna Magnússonar 1990), which still exists for most of Iceland and has been recently converted to digital format (Edvardsson 2001). The Jarðbók entries provide farm-by-farm details of early-18th-century stock raising and wild resource use; furthermore, they retain some elements of medieval land valuation systems (Friðriksson 2004a). However, until the 12th century, none of the medieval written sources are contemporary with the events they describe, and they are problematic sources for the reconstruction of economy and society at Landnám. The first two centuries of Icelandic archaeology are effec-

tively prehistoric and can only be directly investigated by archaeology and paleoecology (Vésteinsson 1998, 2000a).

RESEARCH PROBLEM: UNINTENDED HUMAN IMPACT ON ISLAND ECOSYSTEMS

Iceland has long been famous both for its rich medieval literature and for an extreme human impact on vegetation, soils, and landscapes since its settlement in the ninth century C.E. While Icelanders were composing the prose and poetry that still comprise major sources of the history of the North Atlantic in the Viking Age and a key element in the literary heritage of medieval Europe, they were also participating in massive and often unanticipated alteration of their mid-Atlantic island. It is estimated that 90 percent of the forest and 40 percent of the soil present at the ninth century Landnám has disappeared, and 73 percent of the modern land surface is currently affected by soil erosion (Arnalds et al. 1997). Scores of deflated Viking-age farm ruins now stranded in gravel deserts devoid of trees, grass, and soil bear witness to the complete destruction of the presettlement environment in some parts of the country. The growth of the modern Icelandic economy since 1900 was based largely on fishing rather than agriculture, and in many parts of Iceland today rural farming settlements continue to be endangered by soil erosion begun in the tenth century. The deliberate introduction of the northwestern European Iron age agricultural complex of domestic mammals and crops and the accidental introduction of a host of European insects and wild plants (Buckland et al. 1991a, 1991b) rapidly transformed plant communities not previously subjected to grazing pressure by mammals and created what Paul Buckland has called an “ovigenic landscape” (Buckland 2000). Rapid deforestation often closely followed first settlement (Caseldine et al. 2004; Hallsdóttir 1987) and was, in turn, often followed by soil erosion beginning first at higher elevations and progressing downslope; as groundcover was breached over wider and wider areas, the highly friable Icelandic *andisols* (volcanic soil type) were exposed to wind and water transport (Dugmore and Buckland 1991; Dugmore and Erskine 1994).

The biogeography of the North Atlantic islands may have compounded the environmental assessment efforts of first settlers: Essentially, northwestern European plant communities extend from Norway and the British Isles all the way to southern Greenland (Buckland 2000; Dugmore et al. 2005). A ninth-century colonist coming from coastal Troms district in North Norway (north temperate climate despite its location above the arctic circle) who came hundreds of miles south to settle in Iceland might be excused for failing to immediately recognize that pasture plant communities familiar from home were in fact much closer to their biological range limits in Iceland and thus more vulnerable to grazing pressure. The volcanic *andisols* of Iceland are also subtly different from most soils of the settlers’ homelands and are far more structurally vulnerable to wind and water

transport (Arnalds 1990) and less responsive to fertilization. An “overoptimistic pioneer fringe” of tenth-century settlement may have pushed into the interior highlands only to see vegetation and soils destroyed by the grazing pressure of their imported animals (Sveinbjarnardóttir 1992; but see also Dugmore et al. 2006).

Local populations of walrus in southwest Iceland documented by zooarchaeology also seem to have been killed off in the first few generations of settlement, and wild birds (described as initially “unwary” and easy to kill in later accounts) made up a major portion of animal bone collections (archaeofauna) in southern Iceland (McGovern 1999; McGovern et al. 2001; Perdikaris and McGovern 2005; Vésteinsson et al. 2002). Analysis of a suite of eighth- to 11th-century archaeofauna indicated that colonists were importing a very standardized mix of domestic stock, imposing the same suite of cattle, pigs, goats, sheep, horses, dogs, and cats on every island settled (McGovern et al. 2001). This attempt to transplant a familiar economy to unsuitable ecosystems resulted in the (brief) attempt at pig keeping in Greenland in the 11th century, and substantial piggery lasted in Iceland throughout the tenth century (McGovern 1985; Olafsson et al. 2005). By the time Iceland became a province of Norway in 1264 (following a prolonged civil war among its great magnate families), the country had become a very different place environmentally as well as socially from the Landnám age.

If the marginalization and relative poverty of the later medieval and early modern period had partly environmental roots, then it would appear that the early settlers’ application of ultimately unsuitable models for land management had effectively passed on a crushing bill to their descendants through their early land-use decisions (Amorosi et al. 1997). What happened in the undocumented first two centuries of settlement in Iceland? Or perhaps, more specifically, to what extent did the settlers adapt to their new environment, creating a sustainable economy for themselves, and to what extent did they continue practices developed in a different environment, thus reducing their capacity to produce riches and stability for their community?

“TRADITIONAL NARRATIVE” OF THE LANDNÁM PERIOD (CA. 1990)

By the last decade of the 20th century, sustained multidisciplinary (but mainly single-site) investigations in Iceland had produced what may be called a “traditional narrative,” describing the process of Landnám and its environmental consequences (McGovern et al. 1988 is a representative example).

- Settlement proceeded from coastal enclaves inland, probably following major river valleys in gradual expansion (perhaps sometimes too far) into the interior highlands as less wealthy or successful colonists were pushed out of the most desirable districts.
- First settlers had claimed vast tracts later subdivided among followers, but the individual independent farmer

(*bondi*) and his farm household (so evident in the sagas) were the basic element of settlement and subsistence.

- Human impact on most wild resources was immediate and severe. “Natural capital” (in the sense of Cronon 1991) accumulated since glacial times was rapidly drawn down and expended to finance the rapid expansion of the initially limited numbers of imported domestic stock during the first years of Landnám.
- Deforestation was uniformly rapid; trees were cleared from all but a few belatedly protected areas.
- Almost all manufactured goods were imported, establishing a long-term dependency on continental Europe for iron and other critical materials.
- Cognitive maladies (“false analogy,” “insufficient detail,” “short observational series”) prevented effective adaptation of northwestern European economic expectations to Icelandic realities.
- “Tragedy of the commons” (Feeny et al. 1990) had been played out in the highland pastures, leading to erosion rolling downslope and eventually overwhelming infields and farms.
- Climate cooling in the later Middle Ages impacted a landscape and society already riddled with self-created vulnerabilities and substantially expended natural capital reserves.
- Competition among elites interfered with effective environmental management, pushing tenants into unsustainable practices and eventually destabilizing whole regions.

This narrative certainly evokes parallels in many parts of the modern world, where overgrazing and land degradation affects up to 40 percent of the earth’s vegetated land surface (Brady and Weil 1999). The direct connection of these archaeologically visible processes to both modern Icelandic and global erosion control efforts was used to justify application for global change funding to supplement traditional sources of support for archaeology. Just over a decade later (thanks to this expanded funding), we now recognize that many aspects of the traditional Icelandic environmental Landnám narrative above are simply wrong, that others are clearly oversimplifications, and that the model as a whole needs revision if it is to provide an effective tool for modern landscape managers. These realizations are not the result of gradual accumulation of facts derived from more single-site excavations but, rather, of a sustained program of cross-disciplinary, landscape-scaled investigation made possible by the support of U.S., Icelandic, and U.K. global-change research funding to what became the “Landscapes of Settlement Project” (see Figure 1).

LANDSCAPES OF SETTLEMENT IN NORTHERN ICELAND

The Landscapes of Settlement project began as a single-site investigation centered on the site of Hofstaðir near Lake Mývatn in north eastern Iceland (see Figure 2). Hofstaðir was identified as a potential pre-Christian “temple” site in the 19th century; it was also the site of one of the

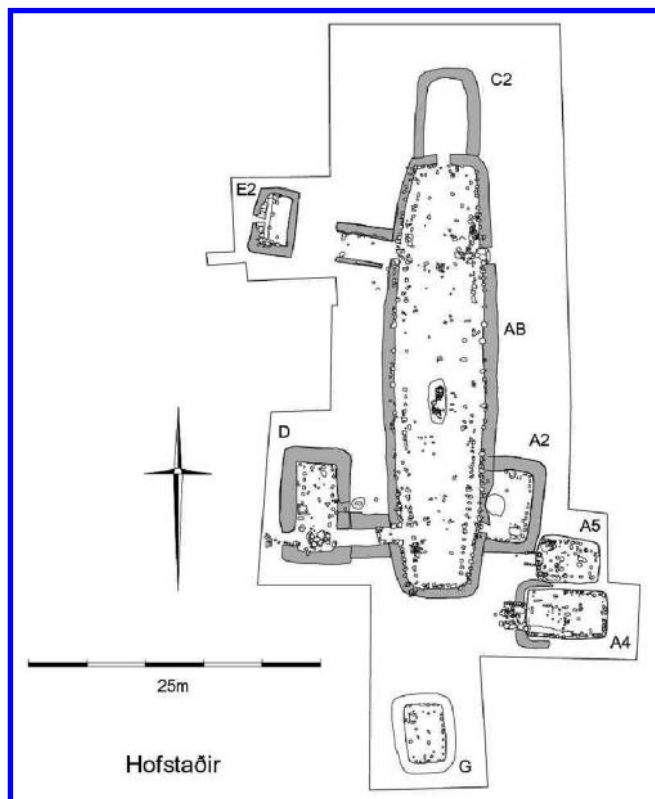


FIGURE 2. Site plan for Hofstaðir. The sunken featured structure G was probably one of the first buildings occupied; it was filled with later midden deposits, as were sunken feature structures A4 and A5 to the east. The structure D was initially a dwelling, but it was used for hay storage by the final phase as the great hall (AB) reached its full size. Structure E2 is a large and well-constructed privy, and the outshot room A2 was used for storage and some smithing. C2 is a medieval structured added after the abandonment of the great hall. Note the indications of benches and interior partitions left by post and stake holes in the great hall and the other buildings. Small sheet middens extended around E2, but most refuse (bone, ash, fire cracked stones, artifacts, etc.) was dumped into the sunken feature structure ruins. (Image courtesy of Gavin Lucas)

earliest fully professional archaeological excavations in Iceland in 1908 (Bruun and Jónsson 1909, 1910, 1911). Daniel Bruun and Finnur Jónsson's partial excavation revealed an exceptionally large long hall (floor area 270 m² whereas most Viking Age halls varied between 60–90 m²) with associated middens whose well-preserved bone collections generated the first professional zooarchaeological report for Iceland (Winge in Bruun and Jónsson 1909). The site was partially reexcavated by Olaf Olsen (1965), who identified it as one of a class of "temple farms": sites that may have seen regular pagan ritual activity but were primarily working farms and elite residences rather than specialized structures like Christian churches or classical Greco-Roman temples. In 1991, teams from the Icelandic Institute of Archaeology led by Adolf Friðriksson (and joined by Vésteinsson in 1995) began what became a multiyear program of open-area excavation (1996–2002) that eventually revealed a complex series of outbuildings and un-

damaged earlier floor layers and which recovered a large well-preserved archaeofauna from stratified contexts, dating from the tenth to early 11th centuries (Friðriksson 1993, 1994; Friðriksson 2004c, Lucas 1998, 1999; Simpson et al. 1999). The collaborative investigations at Hofstaðir conclusively demonstrated that the site was indeed a working farm, where a full range of settlement-age domestic animals were maintained, cooking fires generated ash- and fire-cracked stones in large quantities, and local bog iron was smithed regularly.

However, some finds and faunal patterning also suggest regular ritual activity. During excavation of the wall collapse and the terminal floor layers of the great hall and its outshot rooms, the skulls of 11 cattle, one male pig, one male goat, and one sheep were recovered, all showing depressed fractures between the eyes and marked differences in weathering between front and interior of the skull, suggesting that they had been displayed outside the building for some time before their eventual deposition (see Figure 3). All the cattle and caprine skulls either had horn cores attached or were naturally hornless (a very rare trait in early medieval Nordic stock). Two of the cattle skulls were found face down in the wall collapse, and the rest of the skulls were tossed in a pit in one of the side rooms of the structure during demolition. As part of the demolition process, two sheep were beheaded and both heads and bodies thrown into the same room but were otherwise left unbutchered. Sheep heads were placed in each doorway as demolition was completed, and the great hall was abandoned as the farmstead moved approximately 140 meters to the southwest, next to a newly constructed Christian chapel (whose two basal radiocarbon dates fall around C.E. 1000).

The cattle skulls are unusual in that three are definitely from mature bulls (in the 1712 Jarðabók register the entire Mývatn district had only two immature bulls among 18 occupied farms), and that horn cores were normally broken off skulls to extract the horn for craft work in specimens recovered from midden contexts. Also unusual is the age distribution of the skulls with intact dentition: All are young adult animals around 2.5–3.5 years old (in the "prime beef" age). In most Icelandic archaeofauna from all periods, there is a strong "dairy culling" profile, with a high percentage of newborn calves and old adults (presumably worn-out milkers) dominating skeletal and dental-age indicators. At Hofstaðir, the midden deposits generally conform to this dairy-age profile, but with an overlay of a small but regular addition of cattle also dying in the two–four-year range. Sheep mortality patterns tend to be complicated by a mix of dairying, meat, and wool production strategies, but again Hofstaðir is unusual in the number of "prime meat age" specimens. Although research is ongoing, current zooarchaeological evidence suggests that some regular event (in the early summer) regularly resulted in the death and consumption of cattle and sheep in their prime (thus, not the culling off-take of the normal economy) and the beheading and display of the heads of some cattle and other



FIGURE 3. Bull's skull from wall demolition at Hofstaðir. Depressed fracture between the eyes is typical of these specimens, as is differentially heavy weathering on the outer surface and the intact horn cores. Fractured during 11th-century demolition of the great hall, this partial skull and set of horns seems to have been displayed for some time on the outside of the building. Radiocarbon dates on these skull fragments indicate that they were mounted gradually and not in the same event. (Image courtesy of Tom McGovern)

domestic animals. These patterns are not typical of other Icelandic archaeofauna and would tend to support Olsen's model for a "temple farm," combining normal farming activity with recurring seasonal rituals involving the sacrifice, consumption, and display of major domestic animals whose death would have been expensive in terms of the normal economic cycle as we understand it.

While the excavation program at Hofstaðir progressed, survey teams documented early sites around the lake, eventually documenting over 1,200 sites and structures in the Mývatn region (Mývatnssveit). As test pits and surface collections revealed excellent organic preservation at an increasing number of sites datable to the ninth to 12th centuries in Mývatnssveit, we somewhat belatedly realized that this inland region was particularly well suited to a sustained landscape-scale multidisciplinary investigation. Major excavations (see Figure 1) have taken place at Sveigakot (1999–2006), Hrísheimar (2001, 2003–06), Steinbogi (2002), and Selhagi (2001); mapping and small-scale excavation has been carried out at abandoned farm sites at Oddastaðir, Brenna, and Stong (Edvardsson 2001; Edvardsson and McGovern 2004; Vésteinsson 2000a, 2002, 2003).

Following a thorough revision of the entire Icelandic corpus of grave goods (Eldjárn and Friðriksson 2000), the Mývatn pre-Christian burial sites as well as all (19) such sites in northeastern Iceland have been revisited (Friðriksson 2004b), offering new insights into the development of the Landnám society (Friðriksson 2003, 2004a; Friðriksson et al. 2005a). New studies of burial topography have led to fresh burial finds at Hrísheimar (Friðriksson and McGovern 2005), Daðastaðir (Friðriksson et al. 2005b), Litlu-Núpar (Friðriksson et al. 2005c), and Saltvík (Friðriksson et al. 2005c), from which both artifacts and human and animal bones have been recovered and are now being used to form a new basis for the chronology of the whole region.

Archaeological and paleoecological investigation in Mývatnssveit has been greatly aided by close cooperation with the long-established Mývatn Research Station (affiliated to the Icelandic Ministry for the Environment), which generously provided comparative zoological specimens, steadily expanding low-level air-photo coverage, and a trove of local environmental and cultural information and contacts. Collaboration with geophysicists, geoarchaeologists, and tephrochronologists from Iceland and the United

Kingdom also revealed a complex Holocene environmental history of the region and the presence of a series of datable tephra (notably the Landnám sequence of C.E. 871 \pm 2, a tenth-century *Veidivötn* layer, Hekla 1104 and 1300, Katla 1262, *Veidivötn* 1477 and 1717). Our research, combined with that of Guðrún Larsen and colleagues (2002), has built up an excellent tephrochronological framework that can be used to help answer chronological questions as well as rates of environmental change.

MÝVATNSSVEIT REGION

The Mývatn region (Mývatnssveit) straddles the mid-Atlantic rift and has been volcanically active for thousands of years. The broad shallow lake is fed by underground channels that drain a large area of basaltic lava fields and sand deposits. The groundwater feeding the lake through a number of springs gushing forth along its east shore is rich in phosphate and silica, leading to a luxuriant growth of diatoms and Cyanobacteria (blue-green algae) that support the populations of chironomid and simuliid flies that provide its name ("Midge Lake"). The lake is renowned for rich fishing—mainly of arctic charr (*Salvelinus alpinus*). Despite its altitude of 250–300 meters above sea level (hereafter, asl), the Mývatn district supports rich hay fields around the lakeshore. Today, the highlands around the lake to both the north and south are heavily eroded deserts. Mývatnssveit represents the largest surviving inland farming community in northern Iceland.

The major drainage is the Laxá river flowing northward to the sea approximately 60 kilometers away. The Laxá ("salmon river") is a famous trout stream (*Salmo trutta*); in its lower reaches, it also receives migratory Atlantic salmon (*Salmo salar*), which do not reach the lake area. The Laxá is joined by the Kráká River, which extends southward into the interior highlands; today the region is largely stripped of vegetation and subject to ongoing soil erosion. Many smaller but less fertile lakes surround Mývatn, also providing habitat for charr and trout. Mývatn hosts vast numbers of migratory waterfowl in spring and summer, with currently over 15,000 breeding pairs nesting around the lake. High-quality wet meadow was available around the lake, particularly around Reykjahlíð in the northeast corner of the lake (prior to an 18th-century lava flow) and in a broad periodically flooded marshland with small ponds and streams called Framengjar, a delta created by the Kráká river. Since at least the 18th century, the Kráká has been a destabilized, biologically impoverished, silt-laden, wandering stream, annually transporting tons of sand from the rapidly eroding southern highlands and infilling much of the southern portion of the Framengjar.

When the ninth-century settlers arrived in this interior highland lake basin, they found a somewhat different environment. The hills around the lake were covered with a mixed vegetation of birch woods, heath, grassland, and wetlands. Stands of birch woods probably extended up to at least 400 meters, except for the wet meadows around the

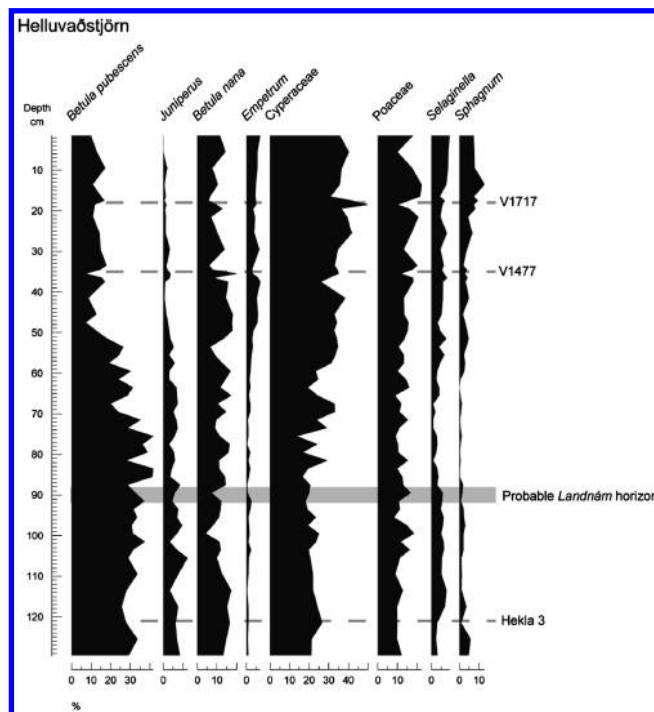


FIGURE 4. Summary pollen diagram from Helluvaðstjörn. Tephra isochrones have been identified by microprobe analysis at Hekla-3, V1477, and V1717. The probable Landnám horizon is marked by the onset of soil erosion within the catchment and by a step change in the productivity of the lake, both of which are presumed to be anthropogenic.

lakeside and the Framengjar (Olafsdóttir and Guðmundsson 2002; Olafsdóttir et al. 2001). At higher elevations to the north and south of the lake, the forest probably thinned out into dwarf-shrub heath lands and arctic-alpine herbaceous vegetation above 400–500 meters, with some copses potentially extending up to 600 meters in elevation.

Geoarchaeological trenches indicate that at least 1.5 meters of redeposited silts now cover the late-ninth-century land surface along the southern edge of the surviving Framengjar wetlands. Distribution of waterfowl and freshwater fish bones in ninth- to tenth-century midden deposits along the Kráká also suggest that the productive ponds, streams, and wet meadows of the Framengjar were once broader and extended further south along the now heavily eroded banks of the Kráká river (McGovern et al. 2006). Pollen evidence from a core taken from Lake Helluvaðstjörn, five kilometers southwest of Mývatn (see Figure 4), suggests that birch woodland was not immediately cleared from the whole region at first settlement but instead persisted for several centuries (Lawson et al. n.d.). Large fragments of burnt wood (including some cross-sections of carbonized birch trunks probably originally about ten cm in diameter) have been recovered from site midden deposits dating from the mid-tenth to later-11th centuries, suggesting that wood lots were still producing fairly substantial trees over a century after first settlement. After the 12th century, such large pieces of charcoal become

rare. At the sites of Sveigakot (at 286 m asl) and Hrísheimar (at 316 m asl), a pattern of tree root casts appearing beneath both the ninth-century Landnám tephra sequence and a midden deposited directly on the Landnám tephra indicated the presence of a fairly dense wood, with trunk spacing about 50–75 centimeters apart. By the time a second tephra fell in the early- to mid-tenth century, the trees were cleared from around the farm sites and the ash covered a leveled midden surface. Human impact had begun in the Mývatn lake basin.

CHRONOLOGY AND SETTLEMENT IN MÝVATNSSVEIT

A growing suite of AMS radiocarbon dates (most on collagen from cattle or pig bones) provide a framework for phasing sites and contexts, especially where the local tephra sequence obviates some of the inherent problems of the tenth-century radiocarbon calibration plateau (see Figure 4). One immediate surprise was the early date for settlement in Mývatn. We have encountered definite midden deposits (including imported domesticates) in direct contact with the late-ninth-century Landnám tephra sequence at Sveigakot, Hrísheimar, Selhagi, and probably Brenna (Vésteinsson 2002). Still further inland (100 km from the coast and over 400 m asl), midden deposits at the abandoned site of Undir Sandmúla in Krokaldalur have also been found in direct contact with the Landnám tephra. Available AMS radiocarbon dates confirm these surprisingly early indications of substantial human presence in the deep interior based on the tephra sequence.

Part of the research program has been the radiocarbon dating (and isotopic analysis) of previously excavated pre-Christian burials in the region and the selective excavation of additional graves (Friðriksson 2000, 2004a, 2004b, 2004c). As many pagan graves included horse and dog skeletons, these domesticates can provide a chronological control even when the human remains produce partly maritime carbon isotope ratios likely to generate “old” dates (Ascough et al. 2006). As Figure 5 and Table 1 illustrate, the horse bones that are associated with Mývatnssveit burials (wholly in the terrestrial food web) produce radiocarbon ages that indicate human occupation of this inland zone in the ninth century. Our old model of a gradual penetration inland by individual households from the coastal zone, driven mainly by population pressure, now looks decidedly unlikely, and we need to consider other approaches to understanding the Icelandic settlement process.

POLITICAL ECOLOGY AND SETTLEMENT PROCESS

Basal radiocarbon dates from the Greenlandic colony (settled from Iceland in the late tenth to early 11th centuries) also indicate surprisingly early occupation of what appear to have always been small, marginal farms in highland valleys or on steep slopes with poor pasture (Arneborg 2000). As in Iceland, the radiocarbon evidence does not support the idea of a very gradual expansion from a few coastal centers but, rather, indicates instead a very swift dispersal within the first

generation of settlement. Orri Vésteinsson and colleagues (2002) discuss these two unexpected patterns for Landnám, suggesting that significant simple population pressure was very unlikely to have produced such early dispersal or such strong resource competition that independent settlers were immediately driven into marginal areas, given the small initial colonizing population. An alternate hypothesis can be drawn from the Icelandic saga accounts of early settlement, particularly the often-cited passage from *Egil's Saga* describing the establishment of the settlement of the chieftain Skallagrim in Borgarfjörður in SW Iceland:

Skallagrim was an industrious man. He always kept *many men with him* and gathered all the resources that were available for subsistence, since at first they had *little in the way of livestock* to support such a *large number of people*. Such livestock as there was *grazed free in the woodland all year round* . . . there was no lack of driftwood west of Myrar. He had a farmstead built on Alftanes and ran another farm there, and rowed out from it to *catch fish and cull seals and gather eggs*, all of which were there in *great abundance*. There was plenty of *driftwood* to take back to his farm. *Whales beached* there, too, in great numbers, and there was wildlife there for the taking at this hunting post: the animals were *not used to man* and would never flee. He owned a third farm by the sea on the western part of Myrar. . . . and he planted crops there and named it Akrrar (Fields). . . . Skallagrim also sent his men upriver to catch salmon. He put Odd the hermit by Gljufura to take care of the *salmon fishery* there . . . When Skallagrim's livestock grew in number, it was allowed to roam mountain pastures for the whole summer. Noticing how much better and fatter the animals were that ranged on the heath, and also that the sheep which could not be brought down for winter survived in the mountain valleys, he had a *farmstead built up on the mountain*, and ran a farm there where his sheep were kept. . . . In this way, Skallagrim put his livelihood *on many footings*.” [Egil's Saga, ch. 29: see Hreinsson 1997, emphasis added]

This image of such a “Skallagrim effect” of chiefly first settlers claiming huge areas and “putting their livelihoods on many footings” by scattering retainers widely into different resource zones recurs in other written accounts, including the apparently comprehensive *Landnámabók* (Book of the Settlements; see Benediktsson 1968). Although such accounts provide a mechanism for the rapid, wide dispersal of small sites over a large area (perhaps initially occupied seasonally or by a very few individuals), it does not adequately explain the pattern of early tephra and radiocarbon dates for both farms and pre-Christian burials in the ninth- to early-tenth-century Mývatnssveit. These are not the isolated dwellings of salmon-fishing hermits but fully established farms with resident lineages wealthy enough to fund elaborate burials of their ranking members. We now need to model a much more rapid and extensive first settlement, certainly involving interacting communities rather than individual pioneers. In addition, we have some reasons to distrust all the literary accounts of the Landnám period. They were all written down 250–300 years after the events described, and modern source criticism has identified many cases of both deliberate political manipulation and

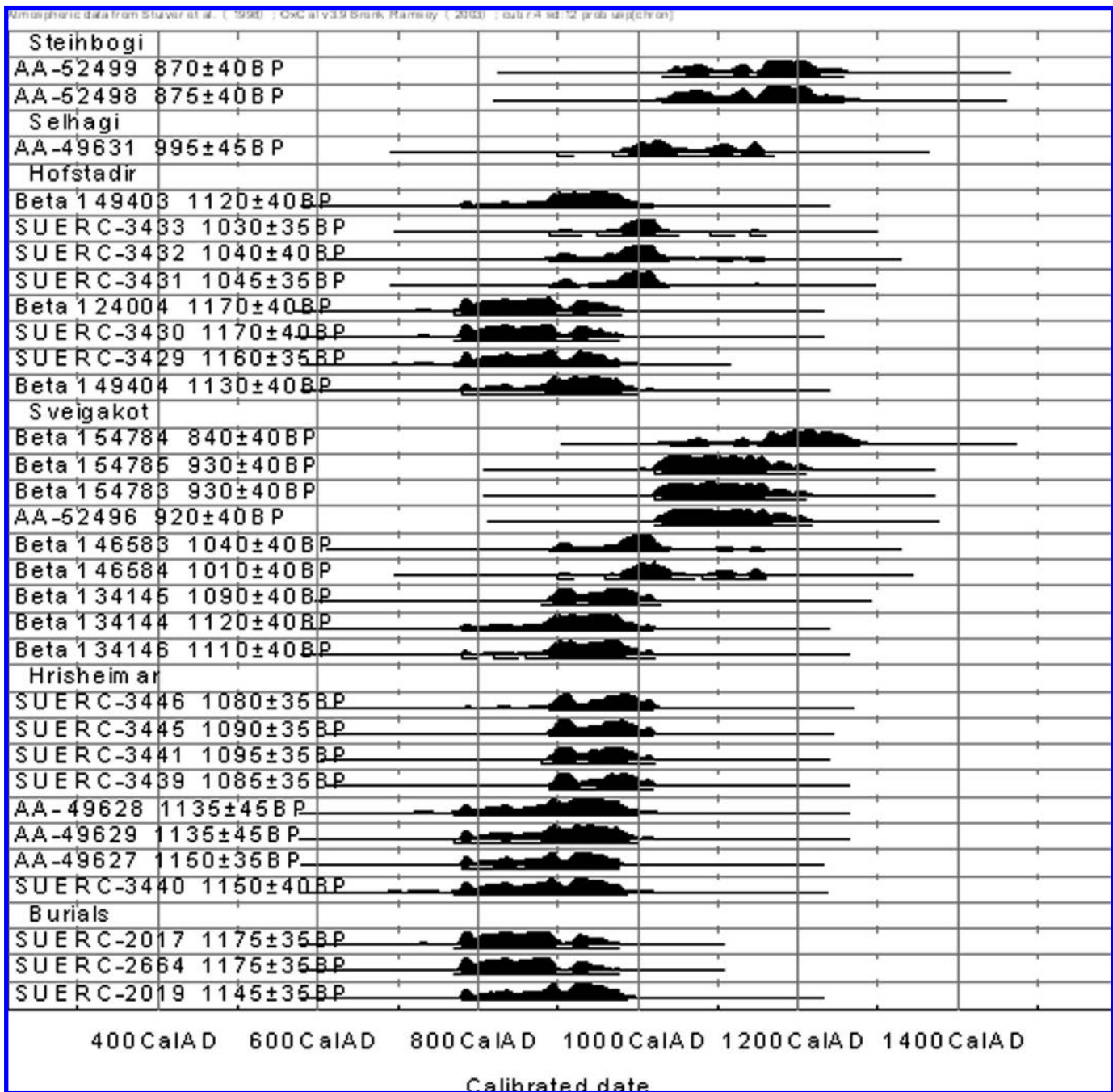


FIGURE 5. Radiocarbon calibration profiles for midden and pre-Christian burial dates from Mývatnssveit with terrestrial isotopic carbon ratios, in stratigraphic order. For laboratory data, see Table 1.

ad hoc filling of gaps by speculative use of then-surviving place-name evidence (see Vésteinsson 2000a for discussion). Although chiefly management of settlement and the settlement pattern was certainly a major factor in Landnám, it probably did not operate exactly as recorded by later scribes.

Vésteinsson (1998, 2000a) has suggested an alternate framework combining social and environmental variables. Given that the densely forested valleys may have been initially unattractive settlement choices compared to wet meadows or existing grass and sedge communities, early set-

tlers may have leapfrogged the valleys in search of farm sites with more immediately available pastures. The higher elevations at the edge of what was then broad upland meadow would have been an attractive settlement zone targeted early by the wealthy and powerful rather than unattractive margins left to underfinanced, overoptimistic fringe settlers (see Smith 1995; Thórarinnsson 1944). Mývatnssveit may have represented a particularly attractive higher-altitude location with its uniquely productive lake ecology. As the valley bottoms became gradually deforested and pasture replaced the dense woodlands of Landnám, the locational

TABLE 1. ^{14}C Ages and Delta ^{13}C Values for Animal Bones from Domestic Middens and Pre-Christian Burials from Mývatnssveit

Lab Reference #	Context & Species	Context Description	Delta ^{13}C (‰)	Delta ^{15}N (‰)	C/N Ratio	Radiocarbon Age (years BP)	95.4% Confidence Range (AD)
DOMESTIC MIDDEN SAMPLES							
Hofstaðir							
Beta 149404	HST G 008 cow	pit house floor	-21.5			1130 ± 40	780–1000
SUERC-3429	HST 7a cow	lower pit house fill	-21.0			1160 ± 35	770–980
SUERC-3430	HST 7a pig	lower pit house fill	-21.0			1170 ± 40	770–980
Beta 124004	HST G 6n cow	lower pit house fill	-21.4			1170 ± 40	770–980
SUERC-3431	HST 6d cow	upper pit house fill	-20.3			1045 ± 35	890–1040
SUERC-3432	HST 6d pig	upper pit house fill	-21.5			1040 ± 40	890–1160
SUERC-3433	HST 6g cow	upper pit house fill	-20.9			1030 ± 35	890–1160
Beta 149403	HST G 004 cow	upper pit house fill	-21.7			1120 ± 40	780–1020
Beta 149405	HST E 1144 cow	outside hall	-21.6			1060 ± 50	880–1160
Sveigakot							
Beta 134146	SVK M 011 cow	lower midden M	-21.0			1110 ± 40	780–1020
Beta 134144	SVK M 002 cow	upper midden M	-21.0			1120 ± 40	780–1020
Beta 134145	SVK M 012 sheep	upper midden M	-19.3			1090 ± 40	880–1030
Beta 146583	SVK T 055 cow	upper fill of pit house T	-22.7			1040 ± 40	890–1160
Beta 146584	SVK T 055 cow	upper fill of pit house T	-21.5			1010 ± 40	900–1160
Hrisheimar							
AA-49627	HRH 003 cow H	midden fill of pit house	-20.7			1150 ± 35	780–980
AA-49628	HRH 003 cow H	midden fill of pit house	-21.0			1135 ± 45	770–1000
AA-49629	HRH 003 cow H	midden fill of pit house	-20.2			1135 ± 45	770–1000
SUERC-3439	HRH 003 cow H	midden fill of pit house	-20.9			1085 ± 35	890–1020
SUERC-3440	HRH 003 pig H	midden fill of pit house	-21.3			1150 ± 40	770–990
SUERC-3441	HRH 003 cow H	midden fill of pit house	-22.0			1095 ± 35	880–1020
SUERC-3445	HRH 060 cow L	lower midden L	-20.9			1090 ± 35	890–1020
SUERC-3442	HRH 002 pig H	deflated upper deposit	-20.1			1120 ± 35	810–1000
SUERC-3446	HRH 002 cow N	deflated upper deposit	-21.4			1080 ± 35	890–1020
Selhagi							
AA-49630	SLH1 01 004 cow	upper midden	-21.1			960 ± 45 BP	990–1190
AA-49631	SHL2 01 004 cow	upper midden	-20.8			995 ± 45 BP	970–1170
Steinbogi							
AA-52498	SBO 002 cow	main surviving midden deposit	-21.4			875 ± 40 BP	1030–1260
AA-52499	SBO 002 cow	main surviving midden deposit	-20.5			870 ± 40 BP	1150–1230
PRE-CHRISTIAN BURIALS							
Gautlönd, Skútustaðir							
SUERC-2026	human GLP-A-1		-19.5	8.4	3.0	1200 ± 35	
SUERC-2663	human GLP-A-1		-19.7	7.7	3.0	1175 ± 35	
SUERC-2664	dog		-20.5	8.3	2.9	1175 ± 35	
Grímsstaðir, Skútustaðir							
SUERC-2018	human GRS-A-1		-19.3	10.0	3.1	1225 ± 35	
SUERC-2019	horse 1967-213		-21.0	1.7	3.1	1145 ± 35	*880–990
SUERC-2662	horse 1967-213		-20.7	1.2	3.0	1105 ± 35	
Ytri-Neslönd, Skútustaðir							
SUERC-2016	human YNM-A-1		-18.9	9.7	3.1	1395 ± 35	
SUERC-2660	human YNM-A-1		-19.3	8.3	3.1	1405 ± 35	
SUERC-2017	horse 1960-46		-21.8	2.7	3.2	1175 ± 35	**770–900
SUERC-2661	horse 1960-46		-21.7	2.0	3.1	1200 ± 35	
Þverá, Reykdælahr							
SUERC-2039	human 2000-3-1		-19.7	8.7	3.1	1235 ± 35	

Note. All calibrations were undertaken using the OxCal Program, which uses the INTCAL98 data (M. Stuiver et al. 1998). All AMS ^{14}C were made on extracted bone collagen.

*calibrated range (95.4% confidence) derived from the weighted mean age of SUERC-2019 and SUERC-2662 (1125 ± 25 yr BP).

**calibrated range (91.4% confidence) derived from the weighted mean age of SUERC-2017 and SUERC-2661 (1188 ± 25 yr BP).

advantages would have shifted, promoting patterns of elite farm distribution more familiar from the medieval records. Air-photo analysis combined with field survey and selected excavation has documented a very extensive system of boundary dikes, which appear to have acted to divide individual holdings and possibly demarcate boundaries of common grazing. Tephra layers indicate that most of these dikes (many of which were two to three meters thick and extended for kilometers across the landscape) were con-

structed in the 11th–12th centuries as part of a very labor intensive program of physical demarcation of cultural landscape. Some of these dikes follow later medieval property or administrative boundaries, but others do not, suggesting changes in the political and economic landscape since their creation. As the natural environment changed and the population of humans and their domestic animals increased, the cultural landscape also adjusted, with the politically powerful certainly striving to amass resources and

followers, but it is difficult to detect the presence of a single dominant chieftain of the Skallagrim sort.

In Mývatnssveit, the 18th-century *Jarðabók* and earlier medieval documents indicate a more complex division of power, with an early chieftain's settlement at Reykjahlíð near the wet meadows of the northeast corner of the lake, while two potential competitors at Grænavatn and Skútustaðir were spaced around the edges of the Framengjar wetlands along the south shore.

A 13th-century saga partially set in Mývatnssveit recounts multiple homicides and repeated, eventually successful attempts to assassinate "Killer Skúta" (the supposed founder of Skútustaðir), but it is unclear how much of the tale relates to ninth- to tenth-century competition and how much to more contemporary later medieval power struggles (Hreinsson 1997). Hofstaðir would make sense as another early chieftain's farm, but tephra running beneath the walls of the great hall make clear that this farm was in fact settled in the mid- to-late tenth century rather than in the first wave of Landnám. The great hall was probably in use for less than a century before being demolished and abandoned in the 11th century. The "temple farm" at Hofstaðir thus appears to be an ultimately failed ploy by a second- or third-generation chieftain to set himself up in competition with the existing power centers at Reykjahlíð, Grænavatn, and Skútustaðir, all of which had access to better quality agricultural land. Well-furnished pre-Christian burials (some with associated weapons and other valuables) and scattered finds of Viking-age luxuries such as amber beads, a copper alloy sword chape (Hrísheimar), and ring-headed pin and silver pendant (Hofstaðir) from floor and midden suggest a comfortable level of prosperity on many of the early settlement farms. When earlier patterns of chiefly competition were consolidated by the formation of the parish structure in the 12th century, both Reykjahlíð and Skútustaðir signaled their triumph by erecting parish churches. However, the 12th-century parish boundaries were gerrymandered to place both Hofstaðir and Grænavatn in the more distant parish of Reykjahlíð instead of the far closer and more convenient (but then bitterly rival) church farm at Skútustaðir (Vésteinsson 2000a).

Political power in Mývatnssveit seems to have been fairly fragmented from first settlement, with no local paramount chieftain capable of dominating the entire basin emerging. It is difficult to model overcentralized or detached chiefly decision making as a cause for adverse early environmental impact. Current evidence instead suggests at least two or three early chiefly aspirants, probably surrounded by lesser farmers initially capable of playing off competing chieftains against each other (Miller 1990). By the 13th century, Mývatnssveit had become a political backwater marginal to the violent power struggles of the great magnate families based elsewhere. The 18th-century *Jarðabók* record shows far less concentration of wealth and stock on a few farms than is visible in nearby districts, and little apparent variation in household subsistence strategy. Although the district was later known as a refuge during

famines (because of its freshwater fishing), as well as a major source of mined sulfur (for gunpowder and medicinal production), it remained economically marginal until the expansion of tourism and industry in the later 20th century brought a resurgence of prosperity probably not seen since the tenth century.

IRON PRODUCTION AND CHARCOAL MAKING

Air photos have revealed patterns of circular depressions along ridgelines in several parts of Mývatnssveit and the surrounding valleys. Excavation indicates that these are charcoal production pits similar to those documented in southern Iceland (Dugmore et al. 2006), and their density and extent suggests a fairly intensive production that could not be sustained by the few modern stands of surviving birch woods. Detailed archaeobotanical, radiocarbon, and tephra analysis is ongoing from the excavated pits but preliminary results indicate that the charcoal largely consisted of locally grown birch-branch wood cut in late spring to early summer, which may indicate some form of deliberate management of the resource. All of the pits investigated were used prior to the fall of the V1477 tephra that filled the pits.

Recent excavations at Hrísheimar have uncovered evidence of very large-scale iron smelting in the form of a group of smelters and smithy structures clustered on a ridgeline just above the farm ruin, and quantities of production slag and bloomery debris have been recovered from the eroded ridgeline (Edvardsson 2001). The charcoal produced in the pits was very similar in form to the material recovered from the middens at Hrísheimar, suggesting the smelting at the site used locally produced charcoal. It would appear that this now-abandoned Kráká valley farm was heavily involved in iron production and was a major consumer of wood charcoal. Excavations continue at Hrísheimar, but it would appear that one product of Landnám-era Mývatnssveit may have been smelted iron. Although the impact of charcoal making on the birch woods would have been significant, a local iron production industry might also provide incentive to efforts at woodland management, which, perhaps, was in turn reflected in the pollen profile of persisting birch woods on now-barren hillsides at Helluvaðstjörn. In any case, early Iceland was clearly far less dependent on imported iron than it was to become in early modern times, when virtually all metal tools were imported.

PASTURES, SOIL, AND FARMING STRATEGIES

Analysis of regional Mývatnssveit Holocene geomorphology based on multiple soil cores tied together by tephra isochrones indicates that the highlands around the lake basin have undergone repeated phases of vegetation and soil loss and restabilization since deglaciation, suggesting the instability of the region over the long term (Olafsdóttir and Guðmundsson 2002). Following periods of increased sediment accumulation circa 5,000 and circa 2,500 years before present, which Rannveig Olafsdóttir and Hjalti Guðmundsson (2002) relate to enhanced regional erosion,

Mývatnssveit seems to have entered a period of stabilization prior to human settlement. It is possible that in pre-Landnám times, the aeolian sediment accumulation forming the regions' soil was significantly affected by rates of tephra production. Volcanic ash is a major component of the Icelandic andisols, and in prehistoric times when sediment accumulation rates were generally lower than in the last 500 years, the proportion that was derived from reworked tephra falling in the interior barren lands could have been significantly higher. It is notable that the basal ages of soils in the Mývatnssveit region become younger into the interior, a pattern consistent with soil cover extending inland as more and more tephra is deposited in the highlands and reworked downslope to aid soil profile formation. Crucial changes occur with settlement. Generally, across Iceland, aeolian sediment accumulation rates increase, a change that Sigurdur Thórarinnsson (1961) convincingly argued to be a result of soil erosion. Many studies have since reinforced this picture (e.g., Dugmore et al. 2000), suggesting a widespread shift in environmental processes as a result of human impacts, more sediment on the move as a result of the widespread development of erosion patches in vegetated areas, and, as a result, greater rates of accumulation in the reducing areas of surviving vegetation and soil cover.

In contrast to areas of southern Iceland (e.g., Dugmore and Buckland 1991; Dugmore et al. 2000), geomorphological and tephrochronological studies in the vicinity of the archaeological sites along the Kráká (Sveigakot and Hrísheimar) indicate a comparatively limited increase in aeolian sediment accumulation following the Norse settlement of the area. In general, there appears to be a relatively slow increase in regional soil erosion through the Middle Ages; with the exception of some localized episodes of soil erosion prior to 1477, it seems that it was not until after the deposition of the Veidivötn 1717 tephra layer that key local thresholds were crossed. The 18th-century record is characterized by greatly increased accumulation rates (up to 20 times the 1477–1717 rate in some profiles) and the presence of repeated sand layers in the profiles, a feature not present in the older and pre-Landnám soils. In general, therefore, the soil profiles in the area do not suggest that Landnám immediately triggered widespread erosion on the regional scale in Mývatnssveit, and that the catastrophic levels of deflation and erosion visible in the modern landscape postdate C.E. 1700 (see also Einarsson et al. 1988).

Within this broad picture, there is much variability in soil erosion impact on the scale of the individual farm holding, and investigations focused on this scale produce evidence of variability in land management between farms. Olafsdóttir and Guðmundsson's (2002) detailed investigation of accumulation patterns in grazing estates associated with the contrasting early settlements at Hofstaðir and Sveigakot indicate marked differences in human impacts (Simpson et al. 2004). In both locations, there is evidence of an acceleration of soil erosion with settlement through

to circa C.E. 1477. However, at Hofstaðir there was a subsequent reduction in erosion rates to substantially below the regional average, whereas at Sveigakot the acceleration of erosion that began with settlement continued, leaving the area as subarctic desert. Part of the explanation for these differences in settlement impacts is inherent in landscape sensitivities: Presettlement erosion patterns indicate a greater rate of sediment movement at Sveigakot compared to Hofstaðir, but positive land management strategies were also of significance at Hofstaðir. Here, on a continuously occupied farm site, the later reduction in land degradation to substantially below the regional average indicates a household community whose management of livestock involved grazing to minimize negative land degradation impacts (Thomson and Simpson 2006, in press).

Suggestions of early land management within the Hofstaðir estate are not confined to grazing livestock; there is also evidence of fuel resources regulation and management (Simpson et al. 2003; Vésteinsson and Simpson 2004). Micromorphological and image-based analyses of fuel residues found in midden stratigraphies indicates that fuel resources included peat, mineral-based turf, and birch wood but with temporal trends in utilization mix. Residues from low temperature domestic combustion of mineral-based turf are evident throughout midden stratigraphies, although more concentrated in earlier phases. In contrast, peat utilization is almost entirely associated with high, "industrial" temperature combustion and evident throughout the stratigraphy, whereas wood ash residues from low and high temperature combustion become more prevalent in later phases of midden stratigraphies. This latter observation hints that woodland management may have promoted different age structures and densities of woodland, raising productivity for a time.

Although Hofstaðir and Sveigakot are less than 12 kilometers apart, their trajectories of human-stock-vegetation-soil interactions were critically different. The eventual outcomes for the farm households were also different. Hofstaðir is still farmed and was continuously occupied, despite some shifts of the dwelling around its home field. Sveigakot was settled earlier, initially by people living in a series of sunken-featured buildings, which were replaced by a small hall around 60 square meters in floor area in the late tenth century. After some decades it was briefly abandoned, and when reoccupied in the late 11th century, its hall floor area was shortened to circa 35 square meters. In addition, the associated archaeofauna shows changes (emphasizing wool production), which may be associated with declining status or tenantry. The site was completely abandoned by the early 13th century and was only rediscovered by archaeological survey in 1998, as bone and charcoal eroded out of deflating middens surrounded by a denuded rock field (Vésteinsson 2000a). The continuity of farm-management strategy may have been an important factor in preserving the productivity of pasture communities around Hofstaðir, and the changing economic and social fortunes of Sveigakot's household certainly was a factor in the decline and eventual

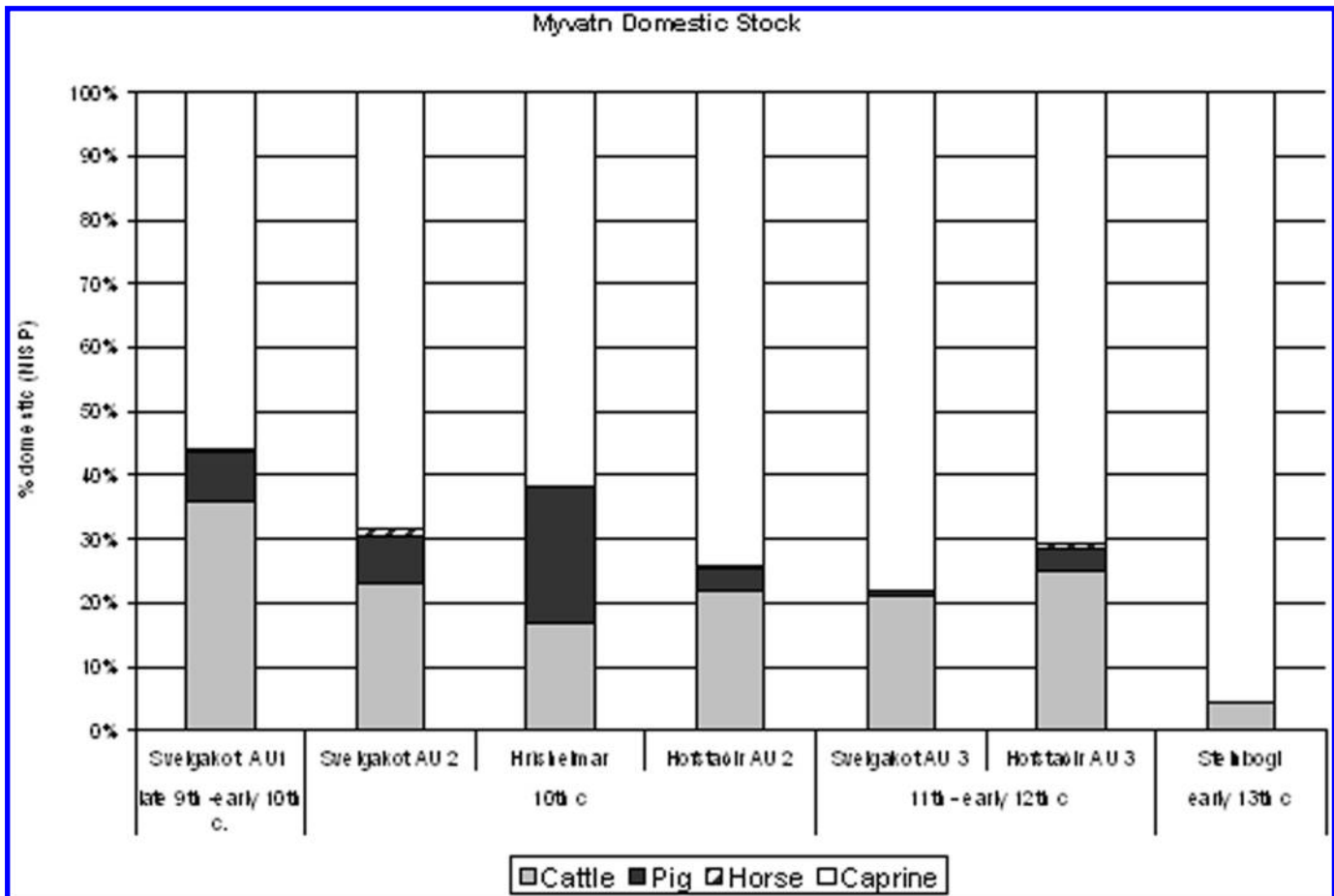


FIGURE 6. Changing relative proportions of domestic mammals from ninth to early 13th centuries for larger Mývatnssveit archaeofauna. Note the decline of pigs and cattle. In the same time period, "caprines" (both sheep and goats together) become nearly all sheep as goats also decline with time, and the farming strategy focuses increasingly on sheep and a limited number of cattle.

destruction of pastures and soil around the farm. In early Iceland, as in so many areas today, human poverty and powerlessness are bad for pastures as well as people.

We now know that animal management strategy did not remain static throughout the period of settlement. Archaeofauna from Hríðheimar, Sveigakot, Hofstaðir, and Selhagi clearly indicate that early settlers of Mývatnssveit did indeed introduce the standard Landnám complex of cattle, sheep, goats, horses, and pigs whose combined grazing, browsing, and rooting would certainly be effective in deforestation—and which, if unchecked, could lead to soil exposure and erosion. However, this initial mix of domesticates was altered during the tenth century, as goats became increasingly rare and pigs were progressively removed from the farmyard, eventually becoming extinct in Iceland (see Figure 6). As the early-13th-century archaeofauna from Steinbogi indicates, there was also a shift away from cattle production toward the sheep-dominated pattern of the 18th-century Jarðabók farms (see Figure 7). Although the early settlers certainly initially introduced a traditional mix of domestic stock familiar from their homelands, they were by no means passive hyperconservative "prisoners of culture" (Descola and Pálsson 1996), incapable of altering their

farming strategy as they gained local experience and as local woodlands (which made pig and goat keeping inexpensive) shrank.

Surviving law codes postdate the Landnám period by centuries but contain a wealth of land-use and stocking legislation clearly shaped by practical experience and extensive case-by-case litigation built up over years. *Grágás* (surviving in late-13th-century manuscripts; see Dennis et al. 1993) makes clear that pigs were by then viewed mainly as "problem animals," ones likely to generate disputes rather than economic mainstays, and detailed land management provisions make equally clear that access and use of common pasturage was by no means open or unregulated. As Ian Simpson and colleagues note, "Regulatory mechanisms were in place to prevent overgrazing from at least the 1200s A.D., with sufficient biomass to support the numbers of domestic livestock indicated from historic sources" (2001:176). Although some aspects of the surviving law codes penalize underuse of pasture vegetation, the overall effect of the laws (if enforced) would be to closely regulate grazing pressure on common pool resource pastures.

Environmental simulation modeling predicting spatial and temporal patterns of vegetation biomass production

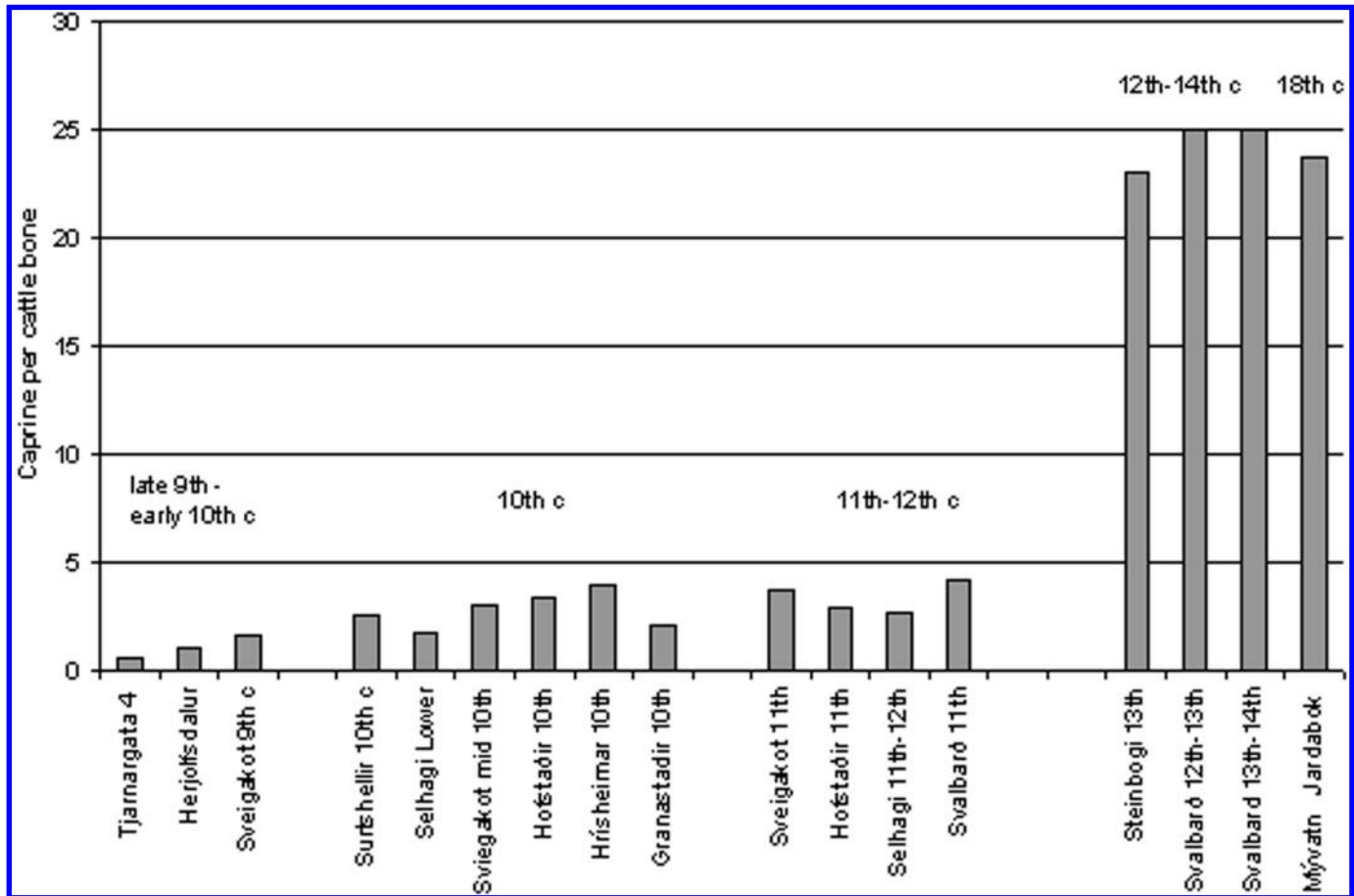


FIGURE 7. Changing ratios of caprine (sheep and goat) and cattle bones from larger archaeofauna spanning the ninth to 14th century in Iceland. The earliest archaeofauna tend to have the highest ratio of cattle to caprine bones, but the pattern differs between regions. Higher status sites tend to have more cattle. The conversion to a largely sheep-based farming strategy appears to occur in the late 12th to early 13th century.

and utilization (*Búmodel*; Thomson and Simpson 2006) has been used to compare landscapes of the Landnám and Jarðabók periods (Simpson et al. 2001; Thomson and Simpson 2006, in press). Observations derived from this approach suggest that there were spatial and temporal variations in productivity within and between historic grazing areas and indicate that land degradation was not an inevitable consequence of the livestock introduced with settlement. The model also clearly indicates that utilizable plant biomass productions in the winter and summer grazing areas far exceeded potential grazing pressure, even when stock numbers were inflated beyond those indicated by archaeology or the Jarðabók record. The critical variable appears to be not total stock numbers, but the timing of the annual removal of flocks in autumn. If animals are allowed to graze even a week beyond the end of grass growth, pasture degradation sets in, leading eventually to breaching of the soil cover and rapid erosion. Correct assessment of the climatically driven onset of winter in the highlands thus appears to have been at least as important as management of total stocking levels.

LONG-TERM SUSTAINABLE MANAGEMENT: WATERFOWL AND EGG COLLECTION

The Mývatn waterfowl nesting area is today a World Heritage site, protected by Icelandic law since 1974, but local residents are still permitted to continue their traditional harvest of duck eggs. Duck-egg harvesting from the nesting grounds around Mývatn is first mentioned in the 1712 Jarðabók entry. The present rule to leave at least four to five eggs in the nest for the female to incubate is first mentioned by a traveler in the area in 1862 (Shepherd 1867), but self-imposed restrictions to harvesting are mentioned some 40 years earlier (Thienemann 1827). The four-to-five egg rule ensures a sustainable yield, as the ducks produce only 0.3–2.8 young per female a year on the average and the overall production of young is regulated by the availability of food in the lake, mainly midges and their larvae and small crustaceans (Gardarsson and Einarsson 1997, 2002, 2004). Today adult waterfowl are still not hunted, but the lakeside farmers collect an average of 10,000 eggs each spring. The zooarchaeological record for ninth- to 11th-century Mývatnssveit indicates that bird bones were a minor element in the archaeofauna (see Figure 8), and what

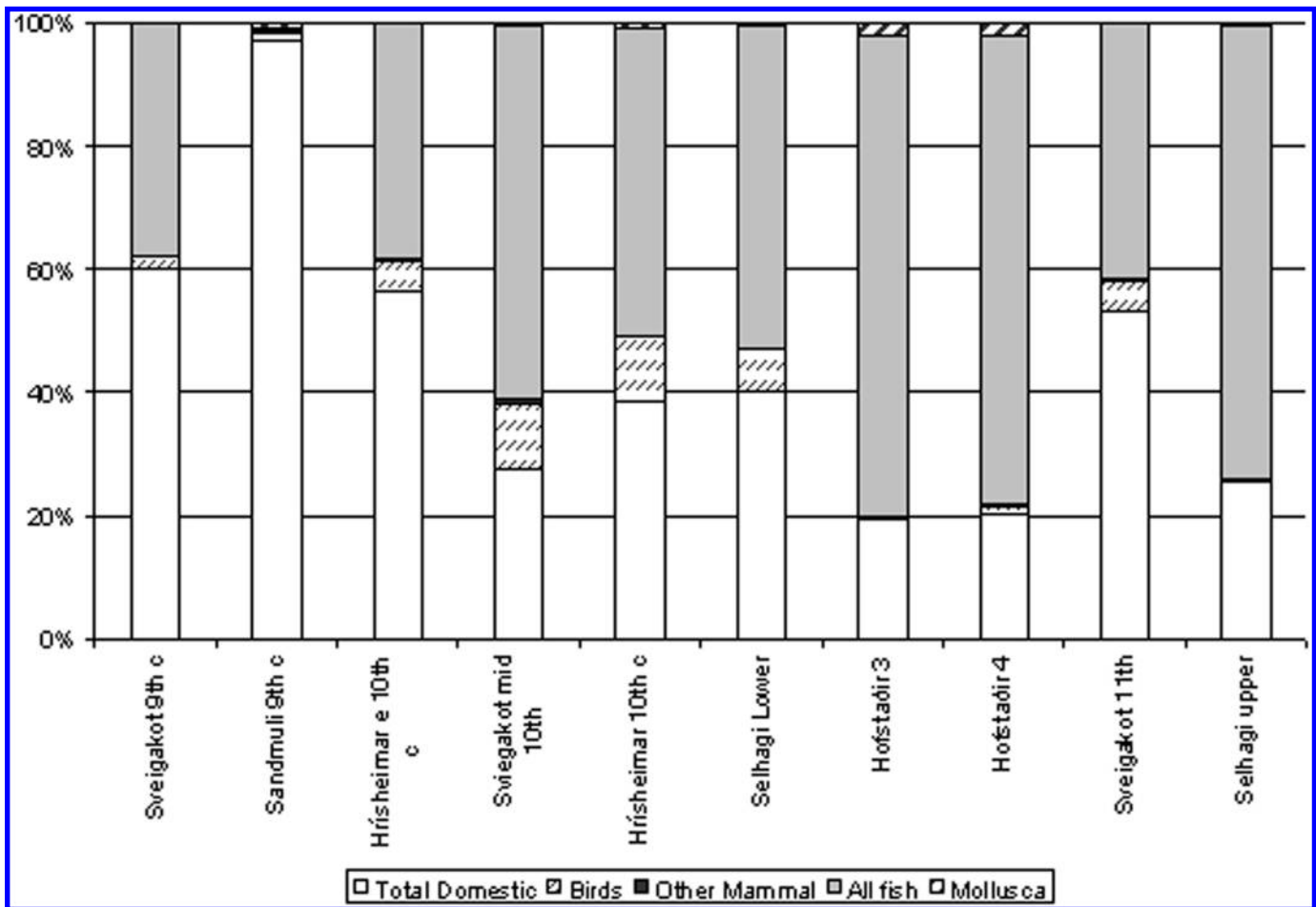


FIGURE 8. Wild and domestic species use in ninth-to-12th-century Mývatn and Krokaldalur. Note the presence of small quantities of bird bones on all sites, nearly all of which are Ptarmigan rather than nonmigratory waterfowl. Marine and freshwater fish bones are common on most sites in the region, outnumbering domestic mammal bones in the Laxá valley area.

bird hunting there was focused in every case on the non-migratory ptarmigan (grouse, *Lagopus mutus*), even at Selhagi in the heart of the waterfowl nesting area. By contrast, the ninth- to 13th-century midden layers at Hrísheimar, Selhagi, Brenna, Hofstaðir, and Steinbogi are rich in bird eggshell, with thousands of fragments recovered from some contexts. Microscopic analysis indicates that the majority of these fragments are from duck eggs, but ptarmigan and seabird eggshells were also present (McGovern et al. 2006). These archaeological data indicate that the successful community management of waterfowl for sustainable egg collection is well over a millennium old (see Table 2). This example of genuinely long-term sustainable wild resource use again conflicts with notions of the inevitability of human draw-down of natural capital following first settlement.

COASTAL CONNECTIONS: SCALES OF INTEGRATION OF THE LANDNÁM COMMUNITY

One surprise in the archaeofauna from inland Mývatnssveit has been the presence of marine species 50–60 kilometers from the nearest salt water. Seal bones have been

found at Hofstaðir and Sveigakot, and a segment of porpoise tail (with butchery marks) was recovered from the late-ninth-century basal layers at Sveigakot. Sea bird bones and seabird eggshell have been recovered from Selhagi, Sveigakot, and Hofstaðir, and tiny mussel shells probably transported attached to seaweed root balls are present in all the Mývatnssveit archaeofauna (McGovern et al. 2006).

However, fish are the most common wild taxa in these inland archaeofauna (see Figure 8). Unsurprisingly, locally available freshwater salmon-family fish (arctic charr and brown trout) make up the great majority of the identified specimens. Fluctuation in the relative abundance of charr and trout in these collections probably relate to complex interactions of local and regional patterns of erosion and deforestation, alteration of streamside and lake-side ecology, changing lake-nutrient cycling patterns, and climate change. A summary of the recent and paleoecological evidence for changes in freshwater fish ecology in Mývatnssveit appears in Lawson et al. 2005, and a cooperative project on long-term biological change in isolated Icelandic salmonid populations is now underway. As in

TABLE 2. Number of Identified Specimens (NISP) Counts with Presence of Masses of Egg Shell ("Egg" above) for Birds from the Major Mývatn Area Sites

Table 2	Site Dates in Centuries	SVK 1 9th-10th	SVK 2 10th	HRH 2 10th	HST 3 10th	SLH 1 10th	SVK 3 11th	HST 4 L. 10th-11th	SLH 2 12th	SBO L 12th- 13th
Anatinidae sp.	Duck sp.			2 + egg	egg	1 + egg	3	1 + egg	egg	
<i>Anas platyrhynchos</i> L.	Mallard		1				3	1		1
<i>Aythya</i> sp.	Scaup or Tufted duck		3				1	1		16
Somateria sp.	Eider duck							2		
<i>Gavia</i> sp.	Diver sp.			1			4			
<i>Gavia immer</i> L.	Great N Diver			2			1			
<i>Gavia stellata</i> L.	Red throated diver						1			
<i>Podiceps auritus</i> L.	Slavonian grebe		1				1			
Anseridae sp.	Goose sp.		2							
<i>Cygnus</i> sp.	Swan sp.		1	2	1	4				
<i>Lagopus mutus</i> L.	Ptarmigan	13	346	230 + egg	16 + egg	3 + egg	338	85	egg	9
<i>Corvus corax</i> L.	Raven		4							
<i>Larus</i> sp.	Gull sp.		2							
<i>Alca torda</i> L.	Razorbill								1	
<i>Uria</i> sp.	Murre or Guillemot				6 + egg			2 + egg	1	
<i>Fratercula arctica</i> L.	Puffin				1					
<i>Alle alle</i> L.	Little auk							3		
Procellariidae sp.	Shearwater or fulmar					egg			egg	
<i>Aves</i> sp.	Bird species indet.	11	274	109	52	13	177	64		33

Note. Although the overwhelming majority of bones are from the nonmigratory Ptarmigan (grouse), there are substantial concentrations of migratory waterfowl eggs. There are both bones and eggshell from seabirds present on several of the sites, indicating the importance of the coastal connection which also brought sea mammal remains and substantial amounts of marine fish to these inland farms.

other areas, zooarchaeological data have proven useful for modern biological conservation efforts (Lauwerier and Plug 2004).

However, bones of marine cod family fish (gadid) make up 12–30 percent of the identifiable fish from the fully quantifiable collections, and their presence in Mývatnssveit clearly relates more to cultural than to natural patterns (McGovern et al. 2006; Perdikaris and McGovern in press). Although the locally available trout and charr are represented by the bones of the whole skeleton, the marine fish have a skeletal element distribution strongly indicating the transport of a prepared fish product. Figure 9 illustrates the bones found on the inland sites relative to the complete fish skeleton. Heads and midbody vertebrae are conspicuously absent. The bones around the gill opening (esp. the dense cleithrum) tend to be left in most dried fish prod-

ucts to keep the filleted upper body together and to aid in spreading the body cavity for drying. This bone element distribution suggests that the Viking-age preserved fish was a flat-dried product (similar to modern Norwegian klipfisk) rather than the round-dried stockfish typical of the later fully commercial international fishery of the 11th–19th centuries. High species diversity within the gadid family is evident in these ninth- to 11th-century inland archaeofauna, including haddock, saithe, and ling, as well as the Atlantic cod, which come to dominate the later medieval to early modern international trade (Amundsen et al. 2005; Perdikaris and McGovern 2005). Similar patterns are visible in Iron Age North Norwegian fisheries, where elites managed an extensive production and local exchange of air-dried fish dating back to the fifth century C.E. (Perdikaris 1999).

In line with the occurrence of freshwater fish, marine mammals and marine fish in archaeofauna are generally dominated by domestic mammals: The $\delta^{13}\text{C}$ results (–18.9 to –19.7 percent), derived from the analyses of human bone collagen from the inland Mývatnssveit pre-Christian burials, indicate a small enrichment over values that would be typical of a wholly terrestrial diet in northern hemisphere and high-latitude populations, and which would tend to indicate some reliance on aquatic resources. Jette Arneborg and colleagues (1999) suggest for population groups from high northern latitudes that a $\delta^{13}\text{C}$ end member of –21.0 percent would be appropriate for a 100 percent terrestrial diet whereas 12.5 percent would represent the end member for 100 percent marine diet. Detailed information on the effect of freshwater fish consumption on human bone collagen $\delta^{13}\text{C}$ values is not well documented. Gordon Cook

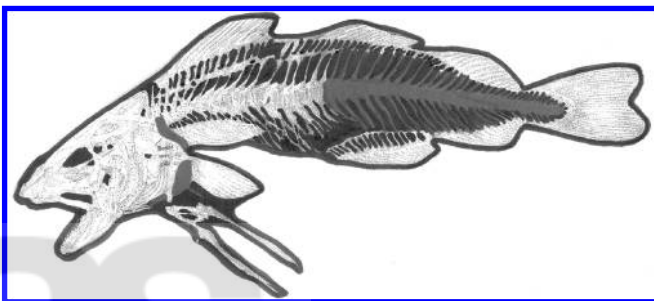


FIGURE 9. Cod skeleton with parts found on the inland Mývatnssveit sites indicated in darker tone. Note that the head and upper vertebral elements are missing, apparently left at a coastal processing site. This pattern is seen uniformly in all Mývatn archaeofauna.

and colleagues (2002) have demonstrated a similar range of $\delta^{13}\text{C}$ values (-18.2 to -19.5 percent) for consumption of significant freshwater resources at Schela Cladovei in the Iron Gates Gorge of the River Danube during the Mesolithic. However, these small shifts in $\delta^{13}\text{C}$ were accompanied by significantly greater shifts in $\delta^{15}\text{N}$ (range = $+13.2$ to $+15.3$ percent; cf. approximately $+8$ percent for a totally terrestrial diet). The Mývatnssveit $\delta^{15}\text{N}$ values were lower in range ($+7.7$ to $+10.0$ percent); however, the shift would depend on the species consumed and its trophic level in the freshwater food web.

Because of the mix of freshwater and marine aquatic resources at Mývatnssveit, it may not be possible to adopt the strategy of Arneborg et al. (1999) to determine the marine 14C reservoir correction in individual humans, based on the $\delta^{13}\text{C}$ results. Furthermore, without evidence to the contrary, we cannot rule out the possibility of a freshwater reservoir effect (Cook et al. 2001). The age offset between the humans and associated horse burials certainly indicate that a reservoir effect does exist. More work is currently under way on the chronology and isotopic dietary reconstruction of Icelandic pre-Christian burials, but at present these data appear to provide confirmation of the role of aquatic products in the diet of inland farmers during the settlement age.

Despite fully established farming and extensive use of local freshwater fish and well-managed egg collection, the eighth- to 11th-century settlers of Mývatnssveit felt the need to regularly provision themselves with marine products. This Viking-age inland distribution of marine products (esp. dried fish) is best documented in Mývatnssveit, but marine fish and sea mammal bones have also been recovered from early inland sites in eastern Iceland (Aðalból; McGovern n.d.), inland Eyjafjörður (Gránastaðir; Einarsson 1994), and in western Iceland (Reykholzt and Háls; McGovern 2004). The inland transfer of marine fish and other marine resources was definitely an established pattern in most parts of tenth-century Iceland. However the acquisition of coastal resources was organized (chiefly staple goods exchange, paired interhousehold transfers, labor service), it appears that even in the earliest days of settlement neither the single farmstead nor even the local district (*hreppur*) was in fact the basic unit of economic survival. We need to consider the role and importance of trade and exchange networks potentially connecting whole quarters of Iceland, and to take seriously the entrepreneurial role of chieftains who were evidently not simply managers of their own prosperous farms. New evidence of early specialized fishing settlements in northwest Iceland further suggest the existence of an extensive distribution network that predates the historical international fisheries of the later Middle Ages (Amundsen et al. 2005; Edvardsson 2001, 2005; Edvardsson and McGovern 2005; Edvardsson et al. 2004; Krivogorskaya et al. 2005; McGovern et al. 2006). In light of these findings, the location of Hofstaðir at the juncture of the lake basin and the route along the Laxá valley to the sea may in itself be significant. Did an aspiring tenth-century chieftain lack-

ing high-quality pasture land attempt to control the flow of marine resources inland as well as playing the religion card?

COMPLICATING CLIMATE INSTABILITY

Until recently, most paleoclimatic data sets had resolution on the order of centuries or millennia, which led to simplistic or deterministic attempts to correlate climate and culture (Grove 1988; McGovern 1991). A major accomplishment of modern climatology has been the development of multiple climatic proxy indicators whose resolution is on the "human scale" of decades, years, or seasons (Jones and Mann 2004; Meeker and Mayewski 2002). In the North Atlantic context, this most notably includes the Greenland Ice Sheet cores. The ice core data requires careful and informed interpretation, but it can be used to document proxy temperatures on the seasonal scale, transforming the debate over climate impact on the extinction of the Norse Greenlanders (Barlow et al. 1997; Buckland et al. 1996). The new high-resolution proxy indicators are not restricted to isotopic temperature reconstruction; they also provide geochemical indicators of sea ice extent and storminess, which suggest that the North Atlantic of the Viking Age was relatively calm and ice free compared to conditions after the 15th century (Dawson et al. 2003).

These multiple high-resolution indicators permit better investigation of key questions as to which aspects of climate change are potentially significant in terms of potential impacts on people. One view is that a year of extremely bad weather (resulting in poor fodder crops or high neonatal fatalities in domesticated livestock) could create issues for some (the poorest and most marginalized settlements), but a sequence of poor weather and repeated losses and poor yields is more likely to create significant problems for many, especially those in marginal environmental or cultural settings (e.g., Parry 1978). Simple economic response models (Farmpack; see McGovern 1991; McGovern et al. 1988) developed for North Atlantic farming economies heavily dependent on stock herding and pasture productivity have indicated that even very extreme events would have been less systemically damaging than a closely spaced series of less extreme, moderately poor growing seasons (Barlow et al. 1997). Sequence and spacing of climate events thus probably mattered more in terms of actual climate impact on North Atlantic medieval economies than did extreme cold spikes.

Perhaps an even more important factor in creating climatic economic impact could be predictability. Northern societies tend to be well buffered against a wide range of climate fluctuation, and demographic records for early modern Iceland reveal considerable resilience and success in containing human mortality, even in the face of combined cold weather and volcanic eruption (Vasey 1996). Effective responses to bad seasons and even to strings of bad seasons were certainly within the competence of the traditional knowledge systems of the Viking Age Icelanders,

and awareness of climatic variability is evident in the medieval law codes and annals (Ogilvie and McGovern 2000). However, the effectiveness of any climate response strategy depends on an ability to reasonably anticipate and predict the behavior of key environmental variables within a tolerable range (such as the end of the growing season in upland pastures), so that key renewable resources are not degraded beyond recovery. Climatic thresholds are famously hard to detect until crossed, and increasing interannual variability continues to adversely affect our own ability to effectively respond to rapid climate change in the modern circumpolar north. Increasing variability and declining predictability of climate–environment–resource interactions definitely stress local resource management strategies of northern peoples today, in some cases creating a frightening sense of devaluation of long-held traditional knowledge bases (Arctic Climate Impacts Assessment 2004). Similar problems in separating signal from noise certainly afflicted medieval communities, and declining predictability must be a key explanation for increased environmental degradation in the generally unstable conditions of the so-called Little Ice Age of the later Middle Ages (Simpson et al. 2001).

A novel way to identify changes in interannual predictability in the GISP2 (Greenland Ice Sheet Project 2) proxy records is through the use of a cumulative assessment of annual deviations from the long-term mean (Dugmore et al. in press). Cumulative measures are generally not used in the analysis of time series of climate data because they add data from one year to the next rather than leaving each season as an independent event. The advantage of a cumulative approach when considering human dimensions is the “memory effect” it simulates: A trajectory indicates change that is potentially predictable, and a “turn over” point highlights a time when the established pattern of the past change is no accurate guide to future trends. In addition, steeper parts of the graph indicate extreme events or rapid change (see Figure 10).

Several key patterns emerge from cumulative assessments of the GISP2 data sets. Some highlight the onset of changes in the later Middle Ages with fundamental climate shifts in the early- to mid-15th century and the extremes of the early 16th century. Others pick out earlier and potentially significant changes C.E. 975–C.E. 1040 and highlight the nadirs of the 18th century (probably linked to the massive erosion visible after the 1717 ash fall). For the farmers of Mývatnssveit, the increase in short-term variability of the tenth to 11th centuries would have been coupled with progressive deforestation, cultural landscape remodeling (probably involving intensive competition among elites), the introduction of Christianity, and a shift in stock-raising strategy away from pigs, goats, and cattle and toward sheep. In this context, it may not be surprising that some medieval land managers got the critical timing wrong for bringing down flocks from uplands or failed to optimally manage winter grazing in the lowlands.

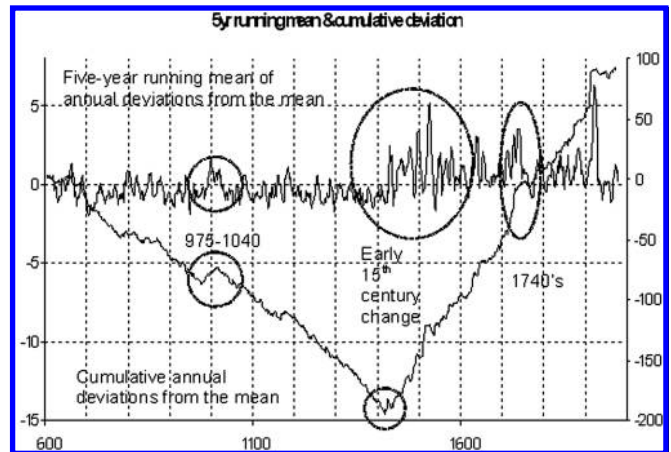


FIGURE 10. GISP-2 proxy storminess data. Deviations from mean PPB Na+ (left-hand scale), cumulative deviations from the mean PPB Na+ (right-hand scale). The cumulative annual deviations from the overall mean show a key change in 1425, a turning point when established patterns of change became a misleading guide to the future. Similar but less sustained changes occurred earlier at 975 and 1040; later, extreme events (e.g., the changes of the 1740s) seem to have become more characteristic.

SUSTAINABLE AND UNSUSTAINABLE RESOURCE USE ON THE MILLENNIAL SCALE

The full results of the NSF “Landscapes of Settlement Project” are still appearing, but we can already offer a number of important corrections to the previously accepted narrative of early settlement and human environmental impact.

- Settlement patterns at Landnám were far more complex than previously realized. Inland settlement (perhaps at what was then the upper boundary between woodland and highland pastures) was early—possibly predating the occupation of the valley systems of the lower elevations. These early settlements were extensive: They probably involved whole communities rather than individual households or chieftains and a few followers. The later documentary sources describing Landnám need reexamination in light of current archaeology.
- Early human impact in Mývatnssveit involved local but not universal deforestation, and clearance may have been more gradual than in southern Iceland. Iron and charcoal production may have provided both additional pressure on forest resources and an incentive to conserve woodland. The reduction in pigs and goats notable in the zooarchaeological record may well reflect efforts to slow forest destruction rather than a simple response to deforestation, as the faunal shift occurs at least a century before pollen evidence for effective deforestation. The most severe erosion is not associated with the initial settlement but, rather, with later Middle Ages and early modern periods.
- Human impact on pasture communities and soils initially was very local. Although the massive erosion catastrophe that began after 1717 has tended to create a

homogenized, deflated, gravel-field landscape in the worst impacted areas around the lake basin, site-focused, intensive soil science investigations backed by impact modeling reveal considerable differences between early management strategies and resulting human impacts in the different farm catchments. It is possible to reconstruct household-level land management practices while integrating these findings with regional-scale indicators.

- Political competition in the first two centuries of settlement was complex, and it appears to have involved a range of strategies including the control of pasture resources, the manipulation of regional staple goods exchange, iron and charcoal production, and investment in pre-Christian ritual and feasting. Following the adoption of Christianity, the clearance of the valley forests for settlement, and the depletion of at least some of the woodlands of the upper elevations, the economic and ritual landscape changed, affecting the political ecology of power and probably permanently relegating upland communities like Mývatnssveit to political and economic marginality. The collapse of the attempted "faith-based" chieftainship at Hofstaðir probably reflected factors beyond the devaluation of an investment in a temple farm by change in cult, including changing patterns of trade and new routes to the sea that bypassed Hofstaðir.
- Although information management maladies associated with colonization of deceptively familiar North Atlantic ecosystems certainly provided unwelcome surprises to early Icelandic settlers, the main cognitive challenges seem to have been associated with changes in climatic stability and predictability after the first century of Landnám. Patterns of land use, traditional herding knowledge, and the critical timing for the end of upland grazing would all be impacted by changes in what had become a well-understood set of environmental parameters. "Tragedy of the commons" is an unlikely explanation for the eventual failure of herding systems to prevent large-scale erosion. Inability to cope with radical increases in environmental variability is far more likely to be the ultimate cause of eventual catastrophic soil loss.
- Not everything went wrong. The Mývatn record indicates significant human response to changing environment, much probably aimed at resource management as well as chiefly aggrandizement. The eventual failure to conserve soils and pasturelands over much of the region can be balanced against the impressive record of successful sustainable management of the migratory bird population of Mývatn. Some remedies were probably applied too little and too late, others may have been frustrated by rapid and unpredictable climate change or by simple inability to predict volcanic eruptions or external political changes. However, the pastures are still green around Hofstaðir, and the waterfowl still come in their thousands each spring to the lake shore. These features of the landscape of Mývatnssveit are as much a result of a thousand years of human environmental management as are the eroded hills beyond the lake.

HISTORICAL ECOLOGY AND MODERN GLOBAL CHANGE

Anthropologists instinctively find attractive the notion that small-scale, traditional societies are good stewards of land and resources. However, "sustainability" of resource use needs to be assessed on the long-time scale of centuries and millennia if we are to avoid simply confusing "serial unsustainability" (Kohler 2004) or cycles of "rape, ruin, and starve" (McGovern 1985) with the near-homeostasis envisaged by modern resource planning. Although there are clearly huge social and technological gaps between Icelandic Viking Age farmers and modern resource managers of global change impacts, some lessons of potentially wide application may be drawn from the Mývatn research:

- **Long-term sustainability is possible.** Millennial-scale sustainable use of waterfowl and their eggs can be documented at Mývatn. This pattern seems to extend to first settlement and certainly provides a demonstration that small-scale, nonstate societies can organize and enforce genuinely sustainable resource use over a thousand years, despite climate fluctuation and severe economic hardship. The long-term record thus contains messages of hope for the future as well as warnings.
- **Continuity and security count.** It is probably no accident that the heavily eroded site of Sveigakot underwent cycles of abandonment and reoccupation at progressively lower-status levels, whereas the still-occupied site of Hofstaðir is still richly vegetated. The geoarchaeological evidence for successful long-term soil management at Hofstaðir certainly reflects in part the continuity of occupation by an upper-middle ranking household. Impoverished farmers with insecure land tenure manage resources differently from secure landowners expecting to pass on inheritance to kin.
- **Predictability is critical.** Successful local-level range management systems that have achieved broadly sustainable patterns of resource consumption for centuries may well be overwhelmed by the simultaneous rapid increases in rate of change coupled with simultaneous decrease in interseasonal predictability. This finding has major implications for modern attempts to sustainably manage agricultural systems in the face of rapid and increasingly unpredictable climate change. Planning for uncertainty is difficult, but this seems a critical need for modern resource managers. Spending more resources on updating older baselines and learning more about past variability is indicated; complacency about "known ranges" of environmental change is not. Sustainable futures are not built on ignorance.

SCIENCE MANAGEMENT LESSONS LEARNED

The experience of committing a decade of international, interdisciplinary effort to Mývatnssveit has provided some humbling lessons. Some of the most difficult issues limiting effective interdisciplinary cooperation (esp. between social

and natural scientists) are the manifold problems of scale matching. Had the investigations been limited to a typical archaeological project of two or three seasons of intensive excavation on a single site combined with a catchment survey, we would have totally misunderstood the larger regional pattern and would have lacked the comparison of nearby sites that provide some basis for sorting out variability caused by time, place, environmental change, and chance. If a broad-brush regional scale approach had been applied, based on site survey backed by a few soil profiles or pollen cores, we would have also come to a largely false appreciation of the actual dynamics of human–environmental interactions in the study area. The marvelous isochrones provided by the well-studied Icelandic tephra have been invaluable, but the single greatest asset to effective integration has been prolonged fieldwork involving sustained focus on a common set of problems within a common research area.

Persistence may matter more than project size: Small, well-integrated teams collecting data for multiple summers (and arguing over analytical patterns each winter) in this case accomplished more effective integration than a single, huge, multi-investigator project limited to a few seasons (the first of which tends to be inevitably spent in logistic and coordination struggles). But however achieved, the size of the different disciplinary data sets does matter greatly; multiple site collections, large ecofact counts, and hundreds of soil profiles all provide the solid basis for cross-disciplinary discussion and integration that is nearly impossible to achieve from a pastiche of small-scale, short-term investigations. If we are to successfully contribute to the archaeology of global change, we need to develop structures of funding and research support that will promote similar sustained, long-term cooperative investigations with a clear landscape focus.

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